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ABSTRACT

The primary purpose of this study was to investigate the effectiveness of two different types of post-instruction concept interviews: one that did and one that did not embed a concept mapping process as means of eliciting students' post-instruction conceptual understandings about the nature of, source of, and problems caused by chlorofluorocarbons (CFCs). The study also tried to determine any effect by the addition of the independent variable, student to expert Pathfinder Network Similarity Index (PFNSI) on the prediction of the criterion measure of accordance (ACCORD). The study also sought to elicit students' perceptions of the process instituted in the interviews to determine what they know. Data was collected from eighth grade physical science students and their teacher using open-ended interviews. Findings indicate an interview that embedded a concept mapping process (compared to an interview that excluded this process) did not affect statistically significant changes in the externalization of students' conceptual understandings. Another finding was that PFNSI had predictive validity for performance in the interview on the measure of ACCORD and proved to be a reliable confirmatory measure of the degree to which students held an ideal post-instructional understanding. Contains 67 references. (JRH)

An Exploratory Study of the Concept Map As A Tool To Facilitate the Externalization of Students' Understandings About Global Atmospheric Change in the Interview Setting

by

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AN EXPLORATORY STUDY OF THE CONCEPT MAP AS A TOOL TO FACILITATE THE EXTERNALIZATION OF STUDENTS' UNDERSTANDINGS ABOUT GLOBAL ATMOSPHERIC CHANGE IN THE INTERVIEW SETTING[1]

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Over the past decade, the concept map has emerged as a versatile and promising tool in the area of science education, especially in research that seeks to investigate students' conceptual understandings (Good, Novak, & Wandersee, 1990; Markham, Mintzes, & Jones, 1994; Novak, 1990a; Wandersee, Mintzes, & Novak, 1994). Concept mapping was developed as a strategy to probe knowledge structures of learners (Driver, 1989), and has further utility as a tool for representing and assessing conceptual understandings, alternatively termed structural knowledge (Jonassen, Beissner, & Yacci, 1993) or cognitive structure (Acton, Johnson, & Goldsmith, 1994). The concept map as a vehicle to represent and assess changes in students' understandings about science was pioneered by Novak and colleagues (Horton, McConney, Gallo, Woods, Senn, & Hamelin, 1993; Novak, 1990b; Novak & Musonda, 1991; Okebukola, 1992).

Novak and Gowin (1984) have recommended three uses of concept maps in concert with interviews to evaluate students' understandings: (a) to inform the development of interview questions, (b) to explicate "post hoc" the student understandings data captured by the interview transcripts, and (c) to assess student understandings as captured in the interview transcripts. Wandersee et al.(1994) cite Novak and Gowin as "see[ing] concept maps constructed from taped interviews as an excellent way to multiply the power of two tools [concept maps and interviews]" (p. 200). These interview-related applications of concept maps have been recommended and applied by several researchers (e.g., Auld, 1990; Brody, 1991; Heinze-Fry, 1987; Novak & Musonda, 1991; Nhkhleh, 1990; White & Gunstone, 1992) and are reviewed in detail elsewhere (Rye, 1995).

Central to the research conducted by this study is the supposition that concept mapping, when employed as an integral component of a concept interview (White & Gunstone, 1992), will facilitate the externalization of students' understandings. In discussing the dimension of availability of knowledge, White (1985) posits that individuals who are equally knowledgeable may differ in their facility to recall relevant elements of that knowledge and that "the source of such a difference is an absorbing realm for

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research . . . if explained, may lead to dramatic improvements in human performance" (p. 56). Accordingly, interview-based research that seeks to investigate another individual's understandings must recognize a critical and central concern, that being the researcher's ability to externalize and describe those particular understandings. The researcher's ability to elicit knowledge is identified widely as a problem area (Cohen, 1991; Firlej & Hellens, 1991; LaFrance, 1992; Pidgeon, Turner, & Blockley, 1991; Swaffield, 1990). In his discussion of methodological difficulties surrounding the interview as a means to measure cognitive structure, Shuell (1985) remarks that "students often are not able to articulate what they know" (p. 123). Pidgeon et al. (1991) quotes Polanyi, who contends that "we know more than we can say" is a significant social science concern. Knowledge elicitation is complicated further by the fact that some knowledge, especially that of experts, is tacit and implicit, making verbalization difficult (Cordingley, 1989; Gordon et al., 1993). The previous are not small concerns, considering that knowledge elicitation is a prerequisite to representing and assessing an individual's understanding (Jonassen et al., 1993).

The concept map is considered to be a graphic metacognitive tool (Johnson & Thomas, 1992; Novak, 1985; Wandersee, 1990; West, Farmer, & Wolf, 1991). As such, the concept map provides an external representation of structural knowledge in the form of a two-dimensional semantic network (Jonassen, 1996), potentially extends working memory, and encourages critical thinking. Furthermore, the concept map as an external representation of structural knowledge serves as a visual image: It may trigger recognition, thereby lowering the threshold of availability and increase recall of knowledge held in long term memory (Ausubel et al., 1978).

Flavell (1985) states that metacognition "includes any knowledge or cognitive activity that takes as its object or regulates, any aspect of any cognitive enterprise" (p. 116). Metacognition includes "strategic actions of the reasoner" (Eylon & Linn, 1988, p. 280), such as questioning, self-checking, and generating alternatives (Johnson & Thomas, 1992). The concept map, as a "mindtool" (Jonassen, 1996), may facilitate such strategic actions in the interview setting. For example, it may cause students to reflect more so on what they know and say, thereby stimulating spread-of-activation and leading to further recall and elaboration (Gagne, 1985; Johnson & Thomas, 1992; Wandersee et al., 1994).

A literature review failed to disclose research that investigated the use of the concept map as an interview tool to enhance students' recall and elicitation of knowledge, relative to the interview questions posed. Wandersee and colleagues (J. Wandersee, personal communication, November 24, 1993) report their development of a "coconstruction of concept map" technique that is deployed in the interview setting. This process has potential to increase the validity of concept map representations of students' understandings that are externalized through interview questions, as opposed to relying on post hoc researcher-constructed concept maps from the student transcripts that represent the "researcher's understanding" of the student's understanding

In the knowledge engineering literature (Smith, 1987), a concept map-like structure--labeled a conceptual graph structure (CGS)--has been employed as a tool in conjuction with interviews to elicit or "extract" knowledge from experts (Gordon & Gill, 1989, 1991; Gordon, Schmierer, & Gill, 1993). This knowledge engineering process is referred to as conceptual graph analysis. Like concept maps, CGS are comprised of nodes connected by labeled links that explicate node interrelationships. Question probes are used in concert with the evolving CGS, the latter serving as an auxiliary visual during the interviews to facilitate elicitation and verification of the expert's understandings. Ultimately, the CGS becomes the "expert" representation of knowledge, and informs the design of text or instruction, or is encoded as the knowledge base in an expert system. CGS and the related analytical process function to minimize any discrepancy or gap between the knowledge engineer's understanding of the expert's knowledge and the expert's actual knowledge. Gordon et al. (1993) report that the utilization of interview question probes in concert with CGS provide a "sensitive means of measuring student knowledge structures" (p. 479). In this study, the investigators adapted the conceptual graph analysis process to design a teacher-expert concept map, which was employed as a referent to analyze student understandings data elicited in the interview setting.

The teacher-expert concept map also was used to identify central concepts for Pathfinder analysis (Schvaneveldt, 1990). Pathfinder Networks are two-dimensional link weighted graphic representations of structural knowledge (Jonassen et al., 1993). Pathfinder Networks are derived through application of the Pathfinder scaling algorithm (Goldsmith, Johnson, & Acton, 1991) to the relatedness ratings of concept pairs-- concept relatedness ratings alternatively are known as pairwise relatedness ratings (Goldsmith et al., 1991) or semantic proximities. The resulting network representations may be compared to yield an index of configurational similarity (Goldsmith et al., 1991) of each student's to the teacher's net--this similarity index alternatively is known as "Closeness" (Acton, Johnson, & Goldsmith, 1994) and is believed to be an excellent measure of students' structural knowledge (Goldsmith et al., 1991; Jonassen, 1993).

The Pathfinder Network is a relatively new tool in educational research (Goldsmith et al., 1991). This study explored new ground by utilizing an expert concept map to inform Pathfinder analysis and in examining the predictive validity of the Pathfinder Network similarity index for student performance in the interview setting. A review of the literature revealed but one study (Wilson, 1994) that has combined the concept map and Pathfinder Network in investigating student understandings in science, and no studies that apply in concert these tools to data analysis in the manner described herein. Wilson employed the Pathfinder scaling algorithm in an investigation of the differences in post-instructional concept maps (on chemical equilibrium) of high and low achievers in high school chemistry. The similarity index of the Pathfinder Networks of the two groups (high and low achievers) was .38. The Pathfinder Network of the high achiever's group had the more broad inclusive concepts located centrally and the more concrete concepts located on the periphery whereas the net of the lower achiever's group placed several of the less inclusive concepts centrally. The author concluded that their results support the claim that "the way knowledge is organized is a major source of the difference between experts and novices" (p. 1143).

Background

This study emerged from research (Rye, Rubba, & Wiesenmayer, 1994, in press) that was conducted as part of a National Science Foundation sponsored Teacher Enhancement Project (Rubba, Wiesenmayer, Rye, & Ditty, 1996). This project sought to develop teacher-leaders and curricula to further Science-Technology-Society (STS) education in middle/junior high school science. The STS issues of focus were global warming and others encompassed by global atmospheric change (Ennis & Marcus, 1994; Houghton, Callendar, & Varne, 1992).

During the early stages of the project, teams of teacher-participants developed STS-global warming "investigation and action" units (Rubba & Wiesenmayer, 1985). Each unit contained lessons that presented STS foundations and a general awareness of STS issues prior to lessons that honed in on investigating and taking action on global warming. As part of formative evaluation of these units, project staff conducted semi-structured interviews (Merriam, 1988; Novak & Gowin, 1984) with grades 5-9 students after they had completed the STS-global warming instruction. These interviews included questions to elicit the students' post-instructional understandings about the nature, cause, and resolution of global warming. Analysis of the interview transcripts incorporated the concept map tool as an "expert" referent structure (Jonassen et al., 1993; Lomask, Baron, & Grieg, 1993) derived from document analysis (Gordon et al., 1993). Additionally, the concept map tool was employed in a small number of the interviews to elicit these students' conceptions about global warming: After the student responded to an interview question, the interviewer asked the student to concept map what the student believed to be the important parts of his/her response. At the close of these interviews, the researchers solicited the students' perceptions of this process as a means to help them answer questions during the interview. The students' responses suggested the merits of the concept map, as process and evolving product, to facilitate the externalization of students' knowledge in the interview setting. Transcript excerpts of students' perceptions follow, which speak to the supposition that the concept map may facilitate metacognition (Flavell, 1985), and elaboration (Gagne, 1985) and explication by the student of their conceptual understanding:

> I think it makes it easier to understand what you are saying.
>
> It [concept mapping parts of my answer] made it clearer so that I could understand what I thought about . When I think about things I just think about things one at a time. This put it all together and I can think about it more clearly.

As I was writing the things and I could see them there, it made me think that there are also more things that made, you know . . . just seeing them helped me think of more things.

[T]hey [concept maps] give you ideas to the answers to the questions.

The experience gained through and the findings (Rye, et al., 1994) from the endeavors described above informed many aspects of the study set forth herein. These aspects included: (a) the development of interview protocols, (b) techniques for data collection and analysis that incorporated the concept map tool, and (c) the choice of cholorofluorocarbons (CFCs) as a subset of the domain--global atmospheric change (GAC)--in which to investigate students' conceptual understandings. Relative to the latter, many of the students who completed the STS-global warming instruction were found to hold alternative conceptions about the role of CFCs in global warming, including the idea that ozone layer depletion is a major cause of global warming (Rye et al., in press). The STS unit (Rubba, Wiesenmayer, Rye et al., 1995) that guided the instruction in this study had been revised to help students restructure such alternative conceptions. These revisions included expanding the scope of the unit to target other GAC issues, e.g., ground level ozone pollution. Accordingly, instruction provided from this revised unit became known as "STS-GAC" instruction, and subsequently is referred to as such.

Additionally, the unit revisions included an increased emphasis on the concept map. Several of the lessons incorporated concept maps and mapping activities. A self-instructional appendix on concept mapping also was included for science teachers, which focused on the "what, why, and how" of concept mapping and developing student competence in this learning strategy.

The individual who served as the teacher-subject and reference "expert" in this study was a veteran science teacher and an exemplary participant in the Teacher Enhancement Project referred to above. She played a major role in the field testing and subsequent modification of the STS-global warming unit, and had considerable interest in the concept map as a science education tool. A volunteer sample of her students served as the student-subjects of this study.

Purpose

The primary purpose of this study was to investigate the effectiveness of two different types of post-instruction concept interviews--one that did or one that did not embed a concept mapping process--as a means of eliciting students' post-instruction conceptual understandings about the nature of, source of, and problems caused by CFCs. In the "type of interview" that included concept mapping, the students were asked to do more than just respond verbally to the interview questions: They also were asked to concept map what they believed to be the important parts of their verbal responses to the interview questions. Additionally, they were encouraged to examine the evolving concept map while considering their responses to the interview questions.

Several dependent variables of conceptual understanding were defined (White & Gunstone, 1992). Chief amongst these was the criterion measure of accordance (ACCORD), which represented the extent to which the student explicated during the interview the concepts and concept relationships that comprised the ideal post-instructional understanding . This ideal understanding was based on the instruction provided by the classroom teacher and was set forth in a teacher-expert concept map. An important research question was, Does an interview that embeds concept mapping, compared to one that does not embed that process, increase significantly ($p < .05$) the externalization of ACCORD? The corresponding null hypothesis was "Type of interview" does not predict ACCORD.

Two other criterion measures (White & Gunstone, 1992) of students' conceptual understanding examined in this study were as follows: (a) external relatedness (EXTERN), as defined by all other GAC concepts set forth in concept maps that were placed at the beginning of each investigation lesson in the STS-GAC unit, and valid concept relationships between the teacher-expert and these other GAC concepts; and (b) interrelatedness (INTER), as defined by the mean number of relationships per concept (Stensvold & Wilson, 1990), where concepts were "teacher-expert" and "other GAC concepts" and relationships were those that comprised accordance and external relatedness of understanding. Research questions and corresponding null hypotheses similar to those that targeted ACCORD were set forth for these additional measures of conceptual understanding, e.g., Does "type of interview" predict EXTERN or INTER?

A secondary purpose of this study was to answer the question, Is there any effect (including interaction) by the addition of the independent variable, student to expert Pathfinder Network similarity index (PFNSI), on the prediction of ACCORD? Corresponding null hypotheses were, (a) The addition of PFNSI to a two-parameter regression model that includes "type of interview " does not improve significantly ($p < .05$) the prediction of ACCORD; and (b) There is no statistically significant ($p < .05$) interaction between PFNSI and "type of interview" as it regards the prediction of ACCORD.

This study also sought an answer for the question, What are the students' perceptions of the process instituted in the interviews as a means to "tell what they know" and what changes do students recommend to improve this process? Detailed findings relative to this question are presented elsewhere (Rye, 1995). However, set forth herein are students' views of the concept map as a tool to "tell what I know."

Methodology

Subjects and Research Design

This study was conducted in a junior high school that was located in a semi-urban area of the northeastern United States. Subjects were an eighth grade physical science teacher and students from four sections of her physical science course. Figure 1 illustrates the research design that guided this study, which is tied to the narrative that follows.

Insert Figure 1 here

Prior to the beginning of the study, the teacher introduced her physical science students to the concept map tool and provided instruction from the foundation and awareness lessons (X_{fa}) in the STS-GAC unit. These lessons did not introduce the concept of CFCs. Subsequently, the teacher recruited student volunteers (S_r) to participate in this study, which surrounded the teaching of the investigation lessons from the STS-GAC unit. These lessons introduced and developed the concept of CFCs and their role in GAC.

All of the student volunteers whose parents provided informed consent and release were scheduled as available and as time allowed for an initial concept interview (O_1). These interviews preceded the start of the STS-GAC investigation instruction, and henceforth are known as the pre-instruction concept interviews (PREICI). A total of 38 students (approximately two-thirds female) completed a PREICI, which was conducted in accordance with a standardized open-ended interview protocol and chiefly for the purposes of removing the novelty to students of the interview setting. The PREICI did not embed a concept mapping process, but did include questions to elicit students' conceptual understandings about CFCs. Accordingly, these interviews generated transcripts that provided evidence of students' understandings about CFCs prior to STS-GAC unit instruction on CFCs. Additionally, the teacher verified that she had not provided <u>any</u> instruction on CFCs in the eighth grade physical science course up to that point, and to her knowledge, the students had not received such instruction in prior science courses.

The week following the completion of the PREICI, the students began instruction from the investigation lessons (X_i) in the STS-GAC unit. This instruction spanned a five week time period. Here, students had the opportunity to learn grade-appropriate science content that underlay the nature, causes, and potential consequences of global warming and ozone layer depletion, and as such, included instruction on CFCs. As part of this instruction, the teacher utilized concept maps to convey GAC content and assigned several concept mapping exercises to the students. However, students were not assigned to develop concept maps in which CFCs were the focus or most superordinate (Novak & Gowin, 1984) concept.

Following the GAC investigation instruction, the students who were present for at least 75% of this instruction <u>and</u> had completed a PREICI were randomly assigned (R_a) to two different "type of interview" groups (GA and GB) and "day of interview" (one of seven school days). Each of GA and GB consisted of 18 students. Seventeen of the students assigned to each group completed a second concept interview (O_2 <u>or</u> O_3), which yielded transcripts of students' post-instruction understandings of CFCs.

Independent two-sample t-tests verified that these two groups did not differ significantly ($p < .05$) on the scaled scores from the grade 7 take of the reading verbal component ($t = -.228$, $df = 31$, $p = .821$) or component total ($t = .406$, $df = 31$, $p = .688$) of the California Achievement Test (CTB McGraw-Hill/. 1986). Additionally, the teacher certified that all students who completed either type of interview were competent in concept mapping. During the timespan that the post-instruction inteviews were conducted. the teacher did not provide any instruction from the STS-GAC unit.

The post-instruction concept interview (O_2) completed by the students in GA was guided by a standardized open-ended interview protocol that was very similar in structure and process to the PREICI: It did not embed a concept mapping process and was considered by the investigator to be conventional in nature. Henceforth, the interview completed by the students assigned to GA was labeled the post-instruction conventional concept interview--POSTICCI. Like the PREICI, the POSTICCI posed questions to elicit students' understandings about CFCs. However, it went beyond the PREICI in that it posed questions to elicit students' perceptions of the interview as a means to "tell what I know."

The post-instruction concept interview (O_3) completed by the students assigned to GB differed in only one respect from the POSTICCI: It was guided by a standardized open-ended interview protocol that was modified to embed a concept mapping process. The interview completed by the students assigned to GB is labeled the post-instruction modified concept interview--POSTIMCI. In addition to an interview transcript, the POSTIMCI yielded student constructed concept maps.

After all of the post-instruction concept interviews were completed, a "paper and pencil" classroom activity was conducted by the teacher with all of her physical science students. Here, students rated the relatedness of all possible pairings ($n = 28$) of the eight concepts that had been deemed by the teacher as those concepts most central to an understanding about CFCs The concept rating activity data from the students participating in this study (O_4) were provided to the investigator, and utilized to generate student Pathfinder Networks and student to teacher Pathfinder Network similarity indexes (PFNSI).

After the completion of the STS-GAC unit instruction from the investigation lessons, the teacher engaged in a knowledge engineering process with the investigator for the purposes of developing the teacher-expert referents (a teacher-expert concept map and Pathfinder Network) used in data analysis. This process is not reflected in the research design (Figure 1), and is presented under the data collection and analysis sections that follow.

Data Collection

All data were collected by the first author of this paper. The tools used to collect data from the students were as follows: (a) the investigator as interviewer (Erlandson, Harris, Skipper, & Allen, 1993), (b) standardized open-ended interview protocols (Patton, 1990) to guide the PREICI, POSTICCI, and POSTIMCI (all interviews were tape recorded); and (c) for the POSTIMCI only, the concept map tool (Novak & Gowin, 1984) and map construction materials (a ceramic dry-erase board, markers, eraser, and blank sticky notes). Additional student data were provided to the investigator by the teacher: the scaled scores and national percentile rankings on select components (test total, reading total, reading vocabulary, and reading comprehension) from the most recent (7th grade) take of the California Achievement Test; and the results from the classroom paper and pencil activity where students rated the relatedness of pairs of central GAC concepts.

Data were collected from the teacher for the purposes of obtaining teacher-expert referents (a teacher-expert concept map and Pathfinder Network) to be used in the analysis of student data. These data were collected through two post-instruction interviews (guided by the protocol used to conduct the POSTIMCI), a concept map and map construction materials, and a paper and pencil exercise that required rating the relatedness of pairs of central GAC concepts.

Investigator

The investigator's experience as an interviewer in and as an analyst of data from research that sought to investigate students' conceptual understandings, including the employment of the concept map tool in such research, was set forth within the background section of this paper. The investigator in this study possessed a sophisticated understanding of GAC relative to the science content that comprised the STS-GAC instruction for the students in this study. In reporting their results from a longitudinal study that incorporated interviews and concept maps to investigate students' science understandings, Novak & Musonda (1991) point to the importance of the interviewer's knowledge base in the content domain in which students' understandings were examined: "We found that it was essential for interviewers to have a sound grasp of the science concepts involved in the interview. . . " (p. 124). A sophisticated knowledge of the content domain, relative to what the students' being interviewed are likely to possess, is critical to the interviewer's formulation and issuance of declarations of complexity (Dana, Kelsay, Thomas, & Tippins, 1992). Such knowledge also is important to data analysis, where the investigator's knowledge is called upon to make decisions about the validity of certain concept relationships explicated in the student interview transcripts and concept maps.

Student Interviews

All interviews were conducted by the investigator in a private setting in the junior high school during normal school hours, were tape recorded, transcribed, and verified against the tape. The PREICI were conducted over a three-day period immediately prior to the start of the STS-GAC investigation instruction and ranged in length from 15 to 25 minutes. The post-instruction interviews (POSTICCI and POSTIMCI) began approximately one and one-half weeks after the completion of the investigation instruction and were conducted over eight sequential school days. The POSTICCI ranged in length from

17.5 to 39 minutes and the POSTIMCI, from 28 to 50 minutes. Approximately equal numbers of each type of interview were conducted on each day.

The complete protocols employed to conduct the PREICI, POSTICCI, and POSTIMCI are provided elsewhere (Rye, 1995). These interview protocols conformed to structural and procedural specifications that have been set forth by recognized authorities in the area of eliciting students' understandings via the interview tool (Novak & Gowin, 1984; Osborne & Freyberg, 1985; White & Gunstone, 1992). For example, the interview questions posed to externalize students' understandings were open-ended, non-leading, and sequenced from somewhat broad to more specific.

These interview protocols evolved from those that were refined over a two-year period by the investigators in the teacher enhancement project research, described previously in the background section of this paper (Rye et al., 1994, in progress). Additionally, a separate study was conducted to pilot-test these protocols. This study is reported elsewhere (Rye, 1995), and resulted in minimal changes to the interview protocols.

The PREICI, POSTICCI and POSTIMCI each were designed to include the following components: (a) a verbal explanation by the interviewer of the nature, confidentiality, purpose, and processes involved in the interview, including that the interview would pose questions about CFCs; (b) up to six minutes of quiet time (Heinze-Fry & Novak, 1990) for the student to think about CFCs and to jot down thoughts and ideas (as single words, phrases, sentences, or diagrams) that they believed were important, for their future reference while answering the upcoming interview questions about CFCs; (c) questions (to be asked by the interviewer) that attempted to elicit students' conceptual understandings about the nature of, sources of, and problems caused by CFCs (Table 1); and (d) the provision by the interviewer of reflective/verification statements in response to the student's answers to the initial asking and one reasking of each question in Table 1.

Insert Table 1 here

The issuance by the interviewer of reflective/verification statements (Dana et al., 1992; Spradely 1979), declarations of perplexity (Dana et al., 1992), and follow-up probes, in response to students' verbal answers to interview questions, were standardized across the POSTICCI and POSTIMCI protocols. The frequency with which the interviewer repeated interview questions and provided reflective/verification statements also was standardized across protocols. Probes and responses other than those set forth in the protocols were avoided by the interviewer. The investigators acknowledge that selective probing of students' responses by the interviewer, in order to investigate more deeply an "interesting remark" made by a student, is a recommended interview practice (Novak & Gowin, 1984; Osborne & Freyberg, 1985; White & Gunstone, 1992). However, in this study, such selective probing would have been a serious limitation, and invalidated comparisons between students completing the POSTICCI and POSTIMCI.

The investigator purposefully designed the protocols that guided the post-instruction concept interviews--POSTICCI and POSTIMCI--to be the same in structure, content, and process, with one principal exception: The POSTIMCI embedded a concept mapping process. The embedding of the concept mapping process translated to three aspects of the POSTIMCI protocol, all surrounding the evolving concept map, that were not a part of the POSTICCI protocol. These aspects were that the POSTIMCI (a) involved the student in constructing a concept map that set forth (as concepts and concept relationships) what he/she believed were important parts of his or her answers to certain interview questions, (b) included dialogue between the interviewer and student relevant to the concept mapping process and what was being mapped, and (c) explicated an evolving visual (the student's concept map) for the student to view and reflect upon as the interview progressed.

Detailed descriptions are provided elsewhere (Rye, 1995) of the procedures employed to conduct the POSTIMCI, which began with orienting the student to the interview-based concept mapping process. At the close of this orientation, the interviewer told the student:

> Since this interview is about CFCs, I will write this (CFCs) concept down on a blank sticky note and I would like you to use it in your concept map. You can use it when you start your map or you can map it in later. This is the only term that I will ask you to use: You will decide all of the other concepts that go in your map.

The sticky note of CFCs was then placed on the side of the dry-erase board that was to be used for the concept mapping. What follows is a summary of the procedures employed, beginning with the first interview question (Table 1), to integrate the concept map construction process with the posing of those questions, the interviewee's verbal responses, and the interviewer's reflective statements:

1. The first interview question was posed. After the student responded, the interviewer issued a reflective response followed by deliberate silence. If the student came forth with additional verbal responses, the interviewer provided corresponding reflective statements. Then, the interviewer asked the student to think about his or her past response(s) and state: "What are a couple of terms (concepts) in what you just said, that you consider to be most important?"

2. The student verbalized the term or terms and the interviewer printed them on separate sticky notes. The sticky notes containing the terms were placed beside the sticky of CFCs, resulting in two to three terms available to start the mapping.

3. The interviewer asked the student to start constructing the concept map by (a) selecting the two terms on stickies that he or she wanted to use to begin the map and (b) mapping in the connection, while thinking about his or her past response to "What are CFCs?"

4. The interviewer told the student that the student could talk about what he or she was mapping in, if he or she so desired, because the interviewer was "interested."

5. The interviewer reminded the student of the following. (a) to not be concerned with how neat the map looked, (b) to not spend too much time in deciding how to map the terms--that the interviewer was more interested in what he or she had to say than in the map--, and (c) that he or she could change the map at any time.

6. If there was another concept remaining on the side of the board, the interviewer gave the student the option of mapping it in, too.

7. The interviewer posed the interview question a second time, which was followed by additional reflective statements by the interviewer and mapping if the student had any further response(s).

8. If the student continued to provide verbal responses to a third and fourth asking of the question, these responses were not reflected or mapped--the interview time block was insufficient to allow for this.

9. The above process (1-8) was repeated through question 3b. The interviewer repeatedly reminded the student that he or she should examine the map while thinking about how to respond to askings and re-askings of each of these interview questions.

10. After the student had no more to say in response to questions 3 through 3b, the student was asked if he or she was satisfied with the map, or if final changes were needed. The student was told to examine the notes he or she had jotted down during quiet time in order to reach this decision. The student subsequently made any changes she or he deemed necessary, and the concept mapping component of the interview came to a close. This process allowed for student verification of the concept map.

11. The concept map remained out on the table for the remainder of the interview, and the student was encouraged to examine the map when considering what responses she or he might make to remaining interview questions (Table 1, questions 4 and 5).

The POSTICCI and POSTIMCI protocols contained questions beyond (and posed after) those set forth in Table 1. These additional questions were for the purposes of (a) assessing the students' ability to transfer their understanding about CFCs to scenarios about atmospheric levels of CFCs and ozone, and (b) eliciting students' "views and opinions" on the interview as a means to "tell what I know." The transfer questions and related findings are presented elsewhere (Rye, 1995). The "views and opinions" questions are presented in Table 2. Because the POSTIMCI embedded a concept mapping process, the set of questions to elicit these students views and opinions was expanded to include those that honed in on the concept map tool (Table 2, "Additional Questions for Students Completing POSTIMCI"). In responding to these "views and opinions" questions, the interviewer encouraged the students to be frank --to not say something just to make the interviewer happy.

Insert Table 2 here

Teacher Interviews

After the teacher finished providing the students with the STS-GAC investigation instruction, two interviews were conducted with the teacher, which embedded processes similar to those described in the knowledge engineering literature by Gordon and colleagues (1989; 1991; 1993) for extracting an expert's knowledge of certain content in a given domain. In this study, these processes were applied to construct an expert referent--a teacher-expert concept map--for use in analyzing a portion of the student interview data, and for determining central concepts for Pathfinder analysis. These teacher interviews are described in detail elsewhere (Rye, 1995) and a summary is presented below.

The POSTIMCI protocol was employed as a guide for the first of these two interviews with the teacher, which resulted in a draft of the teacher-expert concept map. This map explicated what the teacher believed to be the ideal post-instructional understanding that students should hold, relative to the interview questions (Table 1) posed. The interviewer made clear that his intention was not to assess the teacher's knowledge or elicit her personal understanding, but rather to determine what she desired, ideally, the students to know, based on the STS-GAC instruction she provided.

A copy of the draft teacher-expert concept map, along with a copy of the interview transcript and the interview questions (Table 1), were provided to the teacher to reflect on during an 11 day period that lapsed between the first and second interview. During this time, the teacher was asked to note changes (including the addition of cross-links) that she believed were necessary in order for the expert map to reflect better the ideal understanding. The interviewer also studied the transcript and expert map, and identified sections in the transcript and map that warranted probing at the second interview.

The second interview principally was for the purposes of producing a final copy (Figure 2) of this teacher-expert map. Accordingly, the draft map was modified and verified by the teacher during the interview. This final map was employed later by the investigator as an expert referent in constructing templates of concepts and concept relationships, which were applied in the analysis of students' verbal responses (and concept maps in the case of the POSTIMCI) to the questions in Table 1 After the teacher verified the expert map during this second interview, she subsequently identified the 8 concepts that she deemed "most central" to the understanding set forth by the map. These 8 concepts were as follows: global warming, greenhouse gas, UV light, depletion, man made, ozone layer, coolants, and cholorofluorocarbons. These concepts formed the basis of the concept relatedness ratings utilized to generate and compare Pathfinder Networks, as described below.

Insert Figure 2 here

Relatedness Ratings of Concepts

During the planning stages of this study, the investigator explained to the teacher his interest in collecting post-instruction data from student subjects and the teacher that could be used for Pathfinder analysis. Specifically, this data would result from an activity where the students and teacher rated (1 to 9 Likert-type scale) the relatedness (1 = none or very weak and 9 = very strong) of all possible pairings of the 8 concepts deemed as "most central" by the teacher in the teacher-expert concept map (Figure 2). The algorithm [n(n-1) / 2] (Acton, Johnson, & Goldsmith, 1994) for computing the maximum number of concept pairs from some number (n) of individual concepts results in 28 concept pairs, when n = 8.

The teacher was interested in having all of her physical science students complete this concept rating task, and later, use their ratings in a debate-type classroom activity about the relatedness of these concepts. She subsequently agreed to provide to the investigator the ratings of only those students who were participating in the study. Making the task an established part of the science course potentially increased the reliability of the results of the concept relatedness ratings. That is, students likely viewed the activity as being a part of their science course as opposed to a task to complete solely for some research study.

The investigator derived the concept rating activity and related instructions based on the procedures set forth by others (Acton et al., 1994; Jonassen, 1993; Schvaneveldt, 1990) to collect such data for the purposes of producing Pathfinder Networks and obtaining the similarity index of student to expert Pathfinder Networks (PFNSI) Specifically, the ordered list of the 28 concept pairs was derived by, (a) generating a random sequence of the eight central concepts, and (b) entering this random sequence of concepts into the Knowledge Network Organizing Tool (KNOT™, Interlink Inc., 1993) computer program, which in turn generated the ordered list of the 28 concept pairs. The activity/directions were verified by the teacher as something that students readily could understand. Additional explanations/instructions were provided orally by the teacher to help insure that students would take the exercise seriously, and that useable data would result. These instructions included the following: (a) the purpose of the activity (i.e. would be used later in a debate); (b) a practice exercise where students rated the relatedness of concepts comprising familiar concept pairs (e.g., boat-water, boat-land) unrelated to the STS-GAC instruction; (c) taking no more than 15 to 20 seconds to make a decision about the relatedness of any concept pair; (d) to circle "5" on the rating scale if they had no idea of the degree of relatedness between the concepts comprising a given concept pair (Acton et al., 1994).

Thirty-three of the 34 students who participated in the post-instruction interviews subsequently completed the activity. The investigator also administered this activity to the teacher. The teacher followed the same directions as did the students in completing the activity. KNOT™ was used to produce Pathfinder Networks from each student's and the teacher's ratings, and subsequently to compute the similarity index for the teacher's (expert's) and each student's Pathfinder Network (PFNSI). The derivation and use of the PFNSI are described more completely within the data analysis section.

Data Analysis

The POSTICCI and POSTIMCI data (interview transcripts from all students and concept maps from POSTIMCI) were assessed against referent templates to determine the degree to which each student achieved the criterion measures of understanding: ACCORD, EXTERN, and INTER. Specifically, the content of each POSTICCI and POSTIMCI transcript through student responses to interview question 5 (Table 1) was unitized via a case analysis process (Patton, 1990) to determine the presence of the concepts and relationships that comprised the measures of ACCORD and EXTERN, and these concepts and relationships were marked/entered on the data analysis templates (described below). For students completing the POSTIMCI, the concept maps emergent from the interviews also were examined via a case analysis process to identify the presence of any additional teacher-expert concepts and relationships that were not explicated by the student verbally, i.e., were not contained in the interview transcript. The data analysis templates also were marked to reflect the explication of these additional concepts and relationships. The sums of these concepts and relationships marked on the templates were used to derive quantities for the extent to which the criterion measures of ACCORD and EXTERN were present.

The measure of INTER--a ratio of the concept relationships to the concepts explicated--was derived from the concepts and relationships marked on the ACCORD and EXTERN templates. Specifically, the total number of teacher expert relationships plus relationships between teacher-expert and externally related GAC concepts (described below) explicated by the student was divided by the total number of teacher-expert plus externally related GAC concepts explicated by the student. This quotient constituted the ratio INTER.

Bivariate regression analyses (Judd & McClelland, 1989) of data, perfomed using MYSTAT™ (SYSTAT, 1991), were used to make decisions to retain or reject the null hypotheses about "type of interview" prediciting each of ACCORD, EXTERN, and INTER. Multiple regression analyses were performed to determine if students' PENSI improved the prediction of ACCORD, or interacted with "type of interview" in predicting ACCORD. Frequency and inductive analyses (Patton, 1990) were employed to analyze student transcripts to determine their perceptions of the interview as a means to "tell what they knew" (Table 2). The frequency analysis was similar to a classical content or protocol analysis and the inductive analysis took the form of a Grounded Theory approach, where the transcript data was unitized, coded and labeled (Pidgeon et al., 1991). An attempt was made to combine through logical analysis (Patton, 1990) emergent categories (Marshall & Rossman, 1988).

Templates

The templates for assessing ACCORD, EXTERN, and INTER were derived prior to the analysis of any of the post instructional interview data. The teacher-expert concept map (Figure 2) served as the referent for developing the ACCORD templates: and the concepts in the teacher-expert concept map and in the concept maps at the beginning of each STS GAC investigation lesson were the referents for constructing the EXTERN templates.

ACCORD Templates

One template for ACCORD listed the 40 concepts from the teacher-expert map and the second template listed the 45 concept relationships from the map. The analysis of concept relationships as a measure of student understanding from interview transcripts has been described as "concept propositional analysis' (Novak & Gowin, 1984; Posner & Gertzog, 1982) and referred to by others as the use of "expert-derived" or "critical" propositions"(Lomask et al., 1993; Wallace & Mintzes, 1990) or just propositions relative to the knowledge an individual holds about concepts (White & Gunstone). The teacher-expert relationships listed on the concept relationships template included propositions explicitly illustrated on the expert map (e.g., CFCs are used in coolants), explicitly illustrated cross-links (e.g., CFC substitutes may also be greenhouse gas), and propositions that were implicit in the understanding set forth by the expert map. The process whereby implicit propositions were determined, and limitations associated with this process, are described in detail elsewhere (Rye, 1995) and summarized below.

Implicit propositions were instances of two concepts in a progressively differentiated subsection of the expert concept map (Figure 2) hierarchy that were not directly linked, yet could be related in a valid and relevant manner through linking words that existed in that same segment of the concept hierarchy. Examples of implicit propositions were "CFCs are used in air conditioners," "CFCs lead to an increase in global temperature/global warming," and "global warming alters species." The investigator's decision as to what constituted the wording for and realm of implicit propositions was influenced by his immersion in the knowledge engineering process with the teacher to produce the expert concept map, which included a study of the transcripts that resulted from the interviews with the teacher. Additionally, the investigator was influenced by his in-depth knowledge of the STS-GAC unit used as the instruction in this study. Accordingly, a fair cross-validation process (for the determination of implicit relationships) would require other investigators to be equally immersed, involved, and knowledgeable. The fact that the classroom teacher did construct and validate through a reflection process the concept map from which the investigator extracted the relationships did constitute to some degree a validity check.

Concepts and concept relationships explicated by the student that were, in the judgment of the investigator, very similar in meaning to those on the templates were counted as semantic equivalents. Such semantic equivalency included relationships that were asymmetric equivalents, e.g., "Humans make CFCs" is the asymmetric equivalent of "CFCs are Human-made." Furthermore, the decision to judge a concept relationship explicated by the student as the semantic equivalent of a teacher-expert concept relationship was made within the broader context of what the student explicated prior and subsequent to that concept relationship. If such surrounding explications are not considered in the determination of relationship equivalency, then the data analysis is characterized as being an isolated factual approach as opposed to one that is contextualized in the students' broader understanding.

The determination of propositions that are implicit in an expert concept map, and the use of those propositions in analyzing understandings captured by interview transcripts, goes beyond what has been reported elsewhere. Such an analysis accounts for valid and relevant (to the expert map) understandings that may be omitted by referring only to explicitly stated expert or critical propositions (Rye et al., 1994). The taking into account of implicit propositions, similar semantic meanings, and asymmetrically worded relationships for assessment purposes is congruent with the constructivist paradigm that guides this study--it recognizes that knowledge is individually constructed and to varying degrees idiosyncratic; and that expert concept maps should not be "straightjackets" (Lomask et al., 1993, p. 5) for assessment.

EXTERN Templates

The STS-GAC unit investigation lessons that comprised the instruction for this study each contained a concept map, which set forth important understandings about the lesson. There were 141 different concepts in these investigation lesson concept maps. Practically all of the concepts in the teacher-expert map also were in these lesson concept maps. This total of 141 GAC concepts was reduced to 87 concepts by eliminating the teacher-expert (i.e., the ACCORD) concepts as well as several additional investigation lesson concepts that were the semantic equivalents of teacher-expert concepts. These 87 investigation lesson concepts were the externally related GAC concepts, and comprised the concepts template for EXTERN. A second template was derived for the recording of all valid (in the judgment of the investigator) relationships between the EXTERN and ACCORD concepts.

After the investigator completed the analysis of student transcript data against all of the templates, he conferenced with a colleague--the second author of this paper, who also was very familiar with the STS-GAC unit--on a small number of problems that arose during analysis. This colleague helped the investigator to establish procedure to resolve such problems, and the investigator applied such procedure in a second examination of the data. A detailed description of these problems, along with the corresponding decisions applied to the re-examination of the data, are provided elsewhere (Rye, 1995).

PFNSI

The concept relatedness ratings of the 28 concept pairs, completed by each student and the teacher, were entered by the investigator into KNOT™. KNOT™ transformed these ratings, utilizing the Pathfinder scaling algorithm, into a Pathfinder Network for each student and the teacher. The teacher's and example students' Pathfinder Networks are illustrated (as Figures 3-5) within the findings section of this paper. The nodes in these resulting Pathfinder Networks are the eight concepts deemed by the teacher to be those most central in the understanding set forth in the teacher-expert concept map.

These concepts are arranged spatially according to the relatedness ratings (semantic proximities) of the concepts comprising the concept pairs. Two nodes are linked if the scaling algorithms determine that this link explicates the minimum length path between the two nodes.

KNOT™ subsequently was employed to compare each student's to the teacher's net to generate the Pathfinder Network similarity index (PFNSI) for each student. PFNSI is a quantitative measure ranging from 0 (nets have no similarity) to 1 (nets are identical).

Findings and Discussion

Criterion Measures of Conceptual Understanding

Table 3 sets forth descriptive statistics on the degree to which students who completed each type of post-instruction concept interview (POSTICCI or POSTIMCI) explicated the criterion variable measures of understanding: ACCORD, which is the sum of teacher-expert concepts (ACCORDC) and relationships (ACCORDR); EXTERN, which is the sum of externally related GAC concepts (EXTERNC) and relationships (EXTERNR); and INTER, which is the ratio of teacher-expert plus externally related relationships to teacher-expert plus externally related concepts [i.e., (ACCORDR + EXTERNR) ÷ (ACCORDTC + EXTERNC)].

Insert Table 3 here

Bivariate regression analysis where ACCORD was regressed on the independent variable "type of interview" (TYPEITV) failed to reveal TYPEITV as a statistically significant predictor (b = -3.059; p = .467, R^2 = .017), i.e., the interview that embedded a concept mapping process did not result in a statistically significant increase in explication of the teacher-expert concepts plus relationships that comprised accordance of conceptual understanding. TYPEITV also failed to predict the explication of either ACCORDC (p = .310) or ACCORDR (p = .679). Actually, the data in each case appeared to favor slightly the type of interview that did not embed a concept mapping process, as illustrated by comparing the accordance mean values for POSTICCI and POSTIMCI (Table 3).

Bivariate regression analysis where EXTERN was regressed on TYPEITV also failed to reveal TYPEITV as a statistically significant predictor (b = 1.294; p = .542; R^2 = .012). The results paralleled those obtained for accordance of understanding: (a) TYPEITV also failed to predict explication of either EXTERNC (p = .544) or EXTERNR (p = .565), and (b) the data in each case appeared to favor slightly the type of interview that did not embed a concept mapping process.

Bivariate regression analysis where INTER was regressed on TYPEITV failed to reveal TYPEITV as a statistically significant predictor (b = .024; p = .669, R^2 = .006]. However, the data did not appear to favor the POSTICCI group in this case. Potential explanations for the non-significant findings of TYPEITV as a predictor of the measures of conceptual understanding are discussed later under "Students' Perceptions of Interview."

Pathfinder Network Similarity Index in Predicting Accordance

The multiple regression models employed to determine if students' Pathfinder Network similarity index (PFNSI) improved significantly ($p < .05$) the prediction of ACCORD, or interacted with TYPEITV in predicting ACCORD, were built upon the bivariate (two-parameter) regression model utilized to investigate TYPEITV as a predictor of ACCORD. Descriptive statistics on PFNSI for students' completing the POSTICCI and POSTIMCI were, respectively, as follows: $M = .454$ (range of .250-.786), $S.D. = .130$, $M = .444$ (range of .158-.733), $S.D. = .125$. The group means were almost identical; results of the independent t-test ($t = .226$, $p = .823$) showed they did not differ significantly.

The teacher's Pathfinder Network (i.e., the expert referent) against which all students' Pathfinder Networks were compared to generate each students' PFNSI is illustrated below as Figure 3. Figures 4 and 5 illustrate, respectively, the Pathfinder Networks of the two students who had the highest (.786) and lowest (.158) PFNSI values. A visual inspection of the teacher-expert Pathfinder Network (Figure 3) and Figure 4 suggests a high degree of global similarity (Goldsmith et al., 1991) exists between the cognitive structures (relative to the concepts shown) of the teacher and the student with the highest PFNSI. These two nets have 11 links in common and the location of most of the concept nodes (e.g., global warming and man made) is very similar. Each net locates chlorofluorocarbons (CFCs) most centrally, and interlinks it most extensively with neighboring concept nodes.

Insert Figures 3-5 here

Considerable dissimilarity appears to exist in cognitive structure between the teacher and the student who had the lowest PFNSI (Figure 5), with only 3 links common to both nets. This student's net also has fewer total links than either of the nets set forth in Figures 3 and 4. This illustrates that the Pathfinder algorithm, which transformed this student's concept ratings into a structural representation, retained fewer links than was the case for the teacher and student represented by Figure 4. As such, this student's (Figure 5) cognitive structure relative to the concepts shown appears to be less interrelated than that of the teacher or other student. Additionally, unlike the nets in Figures 3 and 4, this student's net interlinks to the greatest degree and locates most centrally the concept node "man-made," with CFCs occupying a space on the periphery. This student also had the lowest ACCORD value of all students who completed the concept interviews. Conversely, the student with the highest PFNSI was considerably above the mean value for ACCORD.

The results from multiple regression analysis, where ACCORD was regressed on TYPEITV and PFNSI, showed that PFNSI improved significantly ($\underline{b}$ = 42.286; $\underline{p}$ = .003; $\underline{R}^2$ = .266) the prediction of ACCORD over a two-parameter model that contained TYPEITV as the sole predictor. The findings from multiple regression analysis that tested for the interaction "TYPEITV x PFNSI" in predicting ACCORD revealed that it was not worthwhile ($\underline{b}$ = 7.004; $\underline{p}$ = .821; $\underline{R}^2$ = .002) adding this predictor to the regression model.

During data analysis, the investigator became interested in whether PFNSI also would improve significantly ($\underline{p}$ < .05) the prediction of students' scaled scores (verbal and total) on their most recent take of the California Achievement Tests (CAT). Post hoc multiple regression analyses showed that PFNSI did improve significantly the prediction of both the verbal ($\underline{p}$ = .001) and total ($\underline{p}$ = .003) CAT scores. These post hoc findings coupled with the fact that PFNSI was a strong predictor of ACCORD lend additional support to the utility of Pathfinder Network structural representations of knowledge, and most specifically the validity of PFNSI, as measures of school learning (Jonassen et al., 1993).

Goldsmith et al. (1991) state that "the validation of a structural assessment should occur within the context of acquiring general classroom knowledge" (p. 94). They also contend that "the validity of the structural approach is better evaluated if the concepts used to derive the structure are only a sample of the set of concepts on which performance is assessed" (p. 94), and state further that such performance assessment should reflect the breadth of understandings and skills that are desired relative to the content area being assessed. In this study, PFNSI was derived from the students' concept relatedness ratings of a critical subset of eight "central" concepts, which were embedded in the measure of accordance (ACCORD) of conceptual understanding. Here, PFNSI correlated strongly ($\underline{r}$ = .515, $\underline{p}$ = .003) to ACCORD. Goldsmith et al. take this correlation as the measure of predictive validity of the structural assessment.

Given the algorithm [n(n-1) / 2, where n equals the number of concepts] for determining the number of concept pairs to be rated to generate the measure of PFNSI, it is ideal if predictive validity for PFNSI can be established based on a relatively small number of representative concepts (Goldsmith et al., 1991). This seems especially important in the case of working with younger learners, where time on task is more of an issue. In this study, a relatively high level (r = .515) of predictive validity was established for PFNSI from the ratings of just 8 concepts (i.e., 28 concept pairs), which were deemed by the classroom teacher as being most central in an expert concept map constructed by that teacher. By comparison, Goldsmith et al. estimated that between 15 and 20 central concepts would be necessary to achieve this level ($\underline{r}$ = .515) of predictive validity for the measure of Closeness on course grades in a college-level research psychology course. Here, subjects rated 30 concepts (i.e. 480 concept pairs) deemed most central to the domain by the instructor, and the resulting predictive validity for Closeness was .74

Goldsmith et al. do not specify what procedure was utilized by the psychology course instructor to extract those 30 "central" concepts from the larger body of domain-specific knowledge. Perhaps the construction and verification by the teacher of an expert concept map in this study facilitated the subsequent selection by the teacher of those concepts that truly were most central to the domain (CFCs and their role in GAC), and accordingly, for which the concept relatedness ratings would ultimately yield a PENSI with substantial predictive power. On the other hand, perhaps the high predictive validity of PENSI for ACCORD was due to the fact that both predictor (PENSI) and criterion (ACCORD) were derived through comparison to teacher-based structural referents--the teacher's Pathfinder Network and "expert" concept map, respectively.

Students Perceptions of Interview

The findings of students' perceptions of the interview process as a means to tell what they knew, as elicited through the questions in Table 2, are presented in detail elsewhere (Rye, 1995). The findings set forth below generally are limited to POSTIMCI students' views of concept mapping as an interview component, and are triangulated with the results from regression analyses in the conclusions section. However, also important to the conclusions of this study was the value that all students ascribed to the "quiet time" for thinking and jotting down thoughts about CFCs prior to the considering the interview questions. This component was perceived as helpful by the most (82%) POSTICCI students ($n = 17$), and by almost 60% of POSTIMCI students ($n = 17$). Students supported this perception with a variety of reasons, ranging from using this think time metacognitively (to brainstorm and organize thoughts), to using the notes as an aid while considering specific interview questions. Prior to reporting the findings of POSTIMCI students' perceptions of the concept map as an interview component, brief attention is given to the structure and variety of concept maps that emerged from these interviews.

Maps Emergent from POSTIMCI

The 17 concept maps prepared by the students during their POSTIMCI varied somewhat in structure and even more so in the number of concepts and concept relationships. The mean number of concepts per map was about 10, with a range of 3 to 17. The number of concept relationships ranged from 2 to 18, with a mean of 9. Few of the concept relationships in any map were explicated as cross-links. Seven of the maps contained no cross links and the remaining 10 maps explicated a mean of 2 cross links.

Figures 6 through 8 are concept maps prepared by three students during the POSTIMCI, and have been selected to illustrate the variety of emergent maps in terms of framework and organization, branching or progressive differentiation of concepts, and cross-linking or integrative reconciliation of concepts (Novak, 1993). Figure 6 illustrates one of the least complex of all concept maps produced by the students. Although it is hierarchically framed, it is basically linear with minimal branching of concepts and no cross-links. Approximately one-half of the maps were chiefly hierarchical in structure, and most explicated more horizontal breadth than the map in Figure 6.

Insert Figure 6 here

Figure 7 illustrates one of the more complex of all maps produced by the students. It is hierarchically framed and represents the extreme in terms of articulating clearly the levels in the concept hierarchy. In many of the maps that were hierarchically framed, it was difficult to discern levels in the concept hierarchy. However, this may have been due in part to the interviewer's remarks to the students to "not worry about being neat." The interviewer did not want students to become preoccupied with neatness, as this would detract from thinking and talking about CFCs.

Insert Figure 7 here

The map illustrated in Figure 8 is a hybrid (West et al., 1991) of web and hierarchical structures, as was the case in several of the other maps. It explicates the extreme in terms of cross-links, but clearly all of the links with arrowheads are not true cross-links. The use of arrowheads on linking lines is a conventio, to distinguish cross-links from other concept relationships (Novak & Gowin, 1984), and the students in this study were appraised of this convention. This map also was interesting because CFCs were not explicated as the focus concept in the map--that concept appears to be "strato. ozone." In the majority of maps produced by the students, CFCs was the focus or superordinate.

Insert Figure 8 here

POSTICMI Students' Perceptions of Mapping

The first interview question (Table 2) to elicit students' perceptions was worded in a very open-ended manner, the intent being to avoid cueing students to think about any specific component. In response, over 40% of the students stated that the concept map was helpful in some way. One of these students, Lucille, speaks to the "graphic organizer" (Wandersee, 1990) feature of a concept map:

> Lucille: And it was good to do a concept map, too, because it kind of helped you sort your thoughts out . . . so you can kind of see what you are thinking

Lucille's comment suggests that she employed the map metacognitively-- as a "strategic action of the reasoner" (Eylon & Linn, 1988)--to help organize her thoughts. Jane infers that the concept map played a role in "spread-of-activation" (Gagne, 1985), leading to further recall of her knowledge:

> Jane: [W]hen I would see this one thing, it would lead to another thing that I would, maybe, didn't think about before.

Questions 2a through 2d (Table 2) attempted to focus students' attention on what they believed was helpful or was in need of change in regards to specific interview components (e.g., notes taken during quiet time, reflective responses provided by interviewer, concept map), and asked them to provide reasons for their answers. Students' responses here were pooled with responses to the first question to determine the prevalence with which all POSTIMCI students perceived specific interview components as helpful. This pooled data revealed that more students (76%) reported concept mapping to be helpful than any other interview component. Reasons provided by the students suggested further the utility of the concept map in fostering metacognition and triggering recall of what they had learned about CFCs. For example, Roberta speaks to the metacognitive nature of the concept map as she identifies it as an image she used to help her monitor and check on the completeness of her recall of knowledge:

> Roberta: Well then, I mean when you look at the map and then you can always find something you missed. If you go over it a second time, then you are usually able to think through your memory and make sure you did not miss anything.

Earl also talked about the map as an image to facilitate recall:

> Earl: [J]ust looking at it and seeing all the words helped me to think of the other terms.

A post hoc inspection by the interviewer of the students' notes, jotted down by the student during the "quiet time," revealed that four (24%) students chose to sketch a concept map (as opposed to just writing notes) as a vehicle to record some of their thoughts during the quiet time. The interviewer did not cue any students about using a concept map as one option for recording their thoughts during the quiet time. He simply stated that the notes might be words, phrases, a diagram--most important was to make the notes "useful to you." However, perhaps the interviewer's mention that students would be constructing a concept map during the interview stimulated this action. Alternatively, perhaps thinking about CFCs brought to mind images of concept maps, or subsets of concept relationships explicated therein, that had comprised a portion of the instruction on CFCs. Regardless, this choice speaks to the value that these students placed on the concept map as a means to help them think and remember about CFCs. Interestingly, a post hoc inspection of the POSTICCI students' "quiet time" notes also revealed that three (18%) students had chosen to "concept map" their notes. Figure 9 illustrates the concept map "notes" prepared by one of these students. In the investigator's opinion, it is unlikely that an eighth grade student could have constructed "from scratch" this entire concept map during the brief (6 minutes) quiet time period, without utilizing mental images of some of the node-link-node networks explicated therein. Accordingly, the investigator believes that components of this student's map had been imaged by the student from science instruction on CFCs. This may have been the case with the other two POSTICCI students who drew concept maps during the quiet note-taking time. One of these other students, Ariel, had this to say about the utility of concept maps:

> Interviewer: Was there anything that comes to mind that helped you remember, think, or talk about CFCs [in this interview]? Anything that you did or I did?
>
> Ariel: The concept maps that Mrs. [my teacher] gave us. Like and she kept telling us to go over them and do them and do all these for homework. So, that kind of helped me. . . .So, that's why like I did that [drew the concept map for my notes], cause I remember. And that's what I did my test on.

Ariel's comment suggests she may have imaged some concept maps from her science class.

Insert Figure 9 here

The remainder of the interview questions for the POSTIMCI students honed-in-on the concept map, in order to elicit further comments on this interview component and to ascertain if and how the concept map might have affected the students answers and thinking to the interview questions. Sixty-five (65) percent of the students said that they believed their answers to the interview questions would have been different than they gave today had the concept mapping not been a component of the interview. Conversely, 29% stated their answers would have been the same. Participants generally were not emphatic in responding one way or the other. One student, Samuel, who said his answers would have been "sort of" the same, added this:

> Samuel: Well, I still, I know in my head but I think that [concept map] helps me see it and how they relate to each other.

Like Samuel, some of the students who believed their answers were different due to the concept mapping inferred that the visual nature of the map was an asset to them while thinking about or responding to the interview questions. Mollie put it this way:

Mollie: [I] could look at what I had said and so I could remember what I didn't say and . . . so I wouldn't leave anything out.

Julia provided evidence of her metacognitive knowledge in referring to the visual nature of the map as a helper in explaining her answers:

Julia: It's easier for me to look at something and explain it than too just think off the top of my head.

Other of these students gave evidence that the visual nature of the map triggered in them the spreading activation process. Carley serves as an example:

Carley: Um, I'd look at one piece of paper--it'd make me think of something else.

The students who believed their answers differed due to the concept map often attributed this difference to the fact that the map or mapping process refreshed their memory or simply helped them to remember. Here, some students referred to the value of the concept connections explicated in the map and that this feature of the concept map was a valuable addition to the notes they had taken during quiet time. Lucille's response serves to illustrate this:

Lucille: Well, whenever we made the concept map, it kind of let me think about what, what I could like connect things from. And that kind of helped me remember what to answer the questions--if I had forgotten some things.

Most of the students who believed that the concept mapping component of the interview did not change their answers to the interview questions stated that the map had no influence on their thinking. These individuals saw the mapping as just restating what they had verbalized, or that the notes they had taken during quiet time had the same influence as did the concept mapping on their answers.

One student suggested that the interviewer could consider giving the students a word list to use in constructing the map. Another student wanted to have a fill-in-the-blank concept map instead of building one from scratch. This student suggested the following as a recommended modification to the concept mapping procedures employed in the interviews:

Jack: Well, I think like you should have- find out what we are doing in science and have like maybe a review thing to help you remember everything. Like make a review concept map where you fill in the blanks, instead of just making up your own from scratch.

Jack's suggestion paralleled some of instructional activities he engaged in to build competence in concept mapping and in studying material from the STS-GAC curriculum, as revealed by the interviews with his teacher:

Interviewer: Now, if you would please tell me, for the concept mapping . . how you developed their [your students'] competence in it.

Teacher. And then I started giving them--at the end of the [science]unit--I would give them a concept map with boxes with connectors in place, some terms in place, and then a list of terms at the bottom that they needed to put in the appropriate box to show that they understood the connection. . . .Then we graduated from that to some with just the boxes filled in and they did the connectors. And then ultimately to just, "Here is a list of terms that you should be able to connect."

Interviewer: Now, in the GAC unit, in general to this point, could you just qualitatively describe the extent of your use of concept mapping. For example, students viewing concept maps, students making concept maps.

Teacher: I took a number of the ones that were in the teaching materials and whited out boxes and after we had gone over a lesson, gave it to them and said, "This is a summary of the lesson and you go back and fill in the boxes". . . .So, I felt for the kids that had difficulty taking notes, as many eighth graders do, that that was there back up. That that became their security blanket.

The STS-GAC curriculum and guide on concept mapping that the investigator provided to the teacher did not suggest this particular application of the concept map tool, however, the investigator has observed other curricula that employ concept maps in this way. The excerpt that follows from the interview with Carley suggests that students did hone-in-on these maps in studying about CFCs and their role in GAC.

Interviewer: Was there anything, be real frank with me, was there anything that was helpful? That is, helped you remember, think and talk about CFC's?

Carley: The concept map helps.

Interviewer: Okay now, for what reason was that helpful to you?

Carley: I'm, like at night time when we're studying this, I'd go home and I'd study it. And it was a lot easier than to have to read you know, the chapters in the books and stuff.

Carley's comment suggests further that she valued the concept map as a study aid. It is likely this value also was held by various other of her classmates. Evidence for this comes from comments made by her teacher during the teacher interviews that followed the completion of instruction:

Teacher: And today, we started a new chapter on simple machines, and that was the first thing they said. Cause I said, "Get out paper we are going to take some notes." They said: "We going to do a concept map?" [Laughter] And I said, "Not right now, we are just going to go with some straight notes."

Interviewer: Do you sense that the majority of them enjoy the concept mapping or not really? Or they seem to ah, you said they ask you

Teacher: Yeah, they seem to enjoy it. They seem to understand it . . .

The investigator also engaged in conversations with the teacher after data analysis, in order to verify further his contention that the students valued concept mapping. Here, the teacher revealed that over one-half of the students who participated in the study went on to develop on their own (i.e., unsolicited by the teacher) concept maps for subsequent units of study in science class. Further, the teacher reported that often these students chose to use such maps as opposed materials developed by the text publisher to study from for science unit examinations.

Conclusions and Recommendations

To the investigators' knowledge, no other studies have employed concept mapping as an interview tool in the manner reported above. Therefore, the conclusions that follow are tentative in nature, and warrant further research. In this study, an interview that embedded a concept mapping process (compared to an interview that excluded this process) did not effect statistically significant ($p <$ .05) changes in the externalization of students' conceptual understandings. Considering the potential impact on cognition of the concept map tool, the investigators' were surprised that the concept mapping process failed to enhance the externalization of students' conceptual understandings. The concept map provides a graphic visual of structural knowledge that, in theory, extends working memory (Johnson & Thomas, 1992; Jonassen et al., 1993). As such, it seems logical that it would trigger spread-of-activation and enhance recall (Ausubel et al., 1978). Furthermore, the act of concept mapping should force critical thinking (Novak & Gowin, 1984), and accordingly, enhance the externalization of interrelationships amongst concepts. The concept map as evolving product and process in the interview setting also should enhance metacognition (Flavell, 1985; Novak, 1990b; Wandersee, 1990).

The investigators' conclude that the following contributed to the finding that the concept mapping component of the post-instruction interviews had no additive effect on students' recall and explication : (a) The quiet time interview component, offered to students prior to the posing of the interview questions, facilitated a state of "mental readiness" and likely enhanced the externalization of all students' post-instructional understandings; (b) The interview topic--CFCs and their role in GAC--was too limited a focus, and as such, did not stimulate or allow for much elaboration; (c) Extensive exposure to concept mapping during STS GAC instruction resulted in students learning well-

"anchoring" in semantic memory (Johnson & Thomas, 1992)--material on CFCs and their role in GAC, and portions of concept maps from instruction may have been imaged (West et al., 1991).

Another factor that might explain these non-significant findings deals with the levels of cognitive outcomes associated with the subject matter. Perhaps the interview questions used to elicit conceptual understandings did not engage sufficiently thinking at the application through evaluation levels, and as such, concept mapping offered no advantage over knowledge that was available due to rote learning (Novak, 1990b). Schmid and Telaro (1990) found that the instructional strategy of concept mapping significantly enhanced performance only on application and analysis level questions.

Other reasons that may have accounted for these findings of non-significance were that (a) concept mapping was still a relatively new strategy for these eighth grade students, and (b) such students are used to rote learning (Novak, 1990b). Novak contends "Junior high school students have become adapted to primarily rote-mode learning and it is not easy to move them to meaningful learning strategies" (p. 41). It is possible that the findings from the interviews may have been different if students would have been involved in constructing their own concept maps over a longer instructional period. Finally, given their exposure during instruction to several concept maps of the "instructor-prepared" variety, it is possible that some students had come to view concept maps on GAC as being somewhat static--more as finite entities than as a tool for elaborating their knowledge. Schmid and Telaro (1990) suggest that the use of teacher-prepared maps will result in "the same kind of rote memorization already so common in the schools" (p. 84). However, the meta-analysis of concept mapping studies by Horton et al. (1993) do not support this contention--they concluded that student prepared concept maps were not superior to instructor prepared maps in effecting student learning gains.

Despite the fact that TYPEITV was not a predictor of any of the students' measures of conceptual understandings, the interview component perceived as helpful by the most POSTIMCI students was concept mapping. The reasons students provided as to why the concept mapping was helpful indicated that they used the map metacognitively and that it triggered the spread-of-activation process. Additionally, the majority of POSTIMCI students believed that the concept mapping component of the interview resulted in their answers to the interview questions being different--and inferred the mapping had a positive impact--from what they would have been had concept mapping been omitted from the interview. Post hoc analyses, where gender and ability level were regressed on categorical predictors coded to reflect the presence or absence of these perceptions (concept map helped or resulted in answers being different), revealed that these perceptions cut across ability level and gender (Rye, 1995).

The investigators recommend that future research should examine the effectiveness of the POSTIMCI protocol with students who are not exposed to any concept maps of the "instructor-prepared" variety, and perhaps not even assigned any concept mapping activities, during instruction on the topic for which understandings are being examined. This condition would necessitate the development and verification of student competence in concept mapping prior to such instruction. Ideal conditions in such a study might also include the following: (a) students would have considerable previous experience in developing concept maps), (b) concept mapping competence would be verified through a task developed and assessed by the investigator, (c) the interview topic would have greater breadth than that in this study, (d) the interview questions would engage more so the application and analysis levels of cognition, and (e) "quiet time" would be examined as an independent variable, i.e., a 4-group design would be employed to allow for the examination of any separate impacts of "type of interview" (i.e. with or without a concept mapping process) and "quiet time" on the externalization of students' conceptual understandings. In regards to the exclusion of explicit illustrations or assignments that involve the concept map tool, once students are competent in concept mapping, the findings of this study suggest that students will employ concept mapping on their own. Therefore, the absence during instruction of such visuals or assignments is no guarantee that instruction will have excluded exposure to concept mapping.

The measure of similarity between student and teacher Pathfinder Networks--PFNSI--was a worthwhile addition to the two-parameter regression model for predicting the measure of accordance (ACCORD). PFNSI had predictive validity (Goldsmith et al., 1991) for performance in the interview on the measure of ACCORD, and proved to be a reliable confirmatory measure (Jonassen, 1993) of the degree to which students held an ideal post-instructional understanding. The predictive validity of PFNSI for ACCORD is considered quiet high, given that only 8 concepts formed the basis of the concept relatedness ratings that were transformed into Pathfinder Networks, and ultimately to the measure of PFNSI (Goldsmith et al., 1991). The investigators infer that the knowledge engineering process of constructing an expert concept map with the teacher facilitated the selection of concepts for Pathfinder analysis that, in the form of concept relatedness ratings, were associated with substantial predictive power.

More research is needed that incorporates the concept map and Pathfinder Network tools. Ideally, such investigations would include a pre- to post-instruction comparison and assessments against expert referent structures. This would make a contribution to the research base that shows students' knowledge structures become more like their instructor's and/or other experts as they develop expertise (Goldsmith & Davenport, 1990). Complementary to this would be research that attempts to replicate or expand the findings of this study, where an expert concept map is utilized to identify domain-specific concepts for concept relatedness ratings, and these ratings are transformed into Pathfinder Network knowledge measures (e.g., PFNSI) and regressed on performance measures to determine predictive validity. Further, such research could build upon that reported by Acton et al. (1994) by employing more than one expert referent for determining PFNSI, and examining whether or not referents other than the instructor resulted in greater predictive validity for PFNSI.

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GA O_2 O_4

X_{fa} S_r O_1 X_i R_a

GB O_3 O_4

<u>Key to Symbols</u>

X_{fa} = Instruction of students from foundation/awareness lessons.
S_r = Student recruitment for study.
O_1 = Concept interviews with students prior to investigation lessons.
X_i = Instruction of students from STS-GAC investigation lessons.
R_a = Random assignment of students completing O_1 and X_i to GA or GB.
GA = Group of students to undergo, after investigation lessons, a concept interview that <u>would not</u> embed a concept mapping process.
GB = Group of students to undergo, after investigation lessons, a concept interview that <u>would</u> embed a concept mapping process.
O_2 = Concept interviews with students in GA after investigation instruction.
O_3 = Concept interviews with students in GB after investigation instruction.
O_4 = Relatedness ratings of GAC concept pairs.

<u>Figure 1</u>. Research design

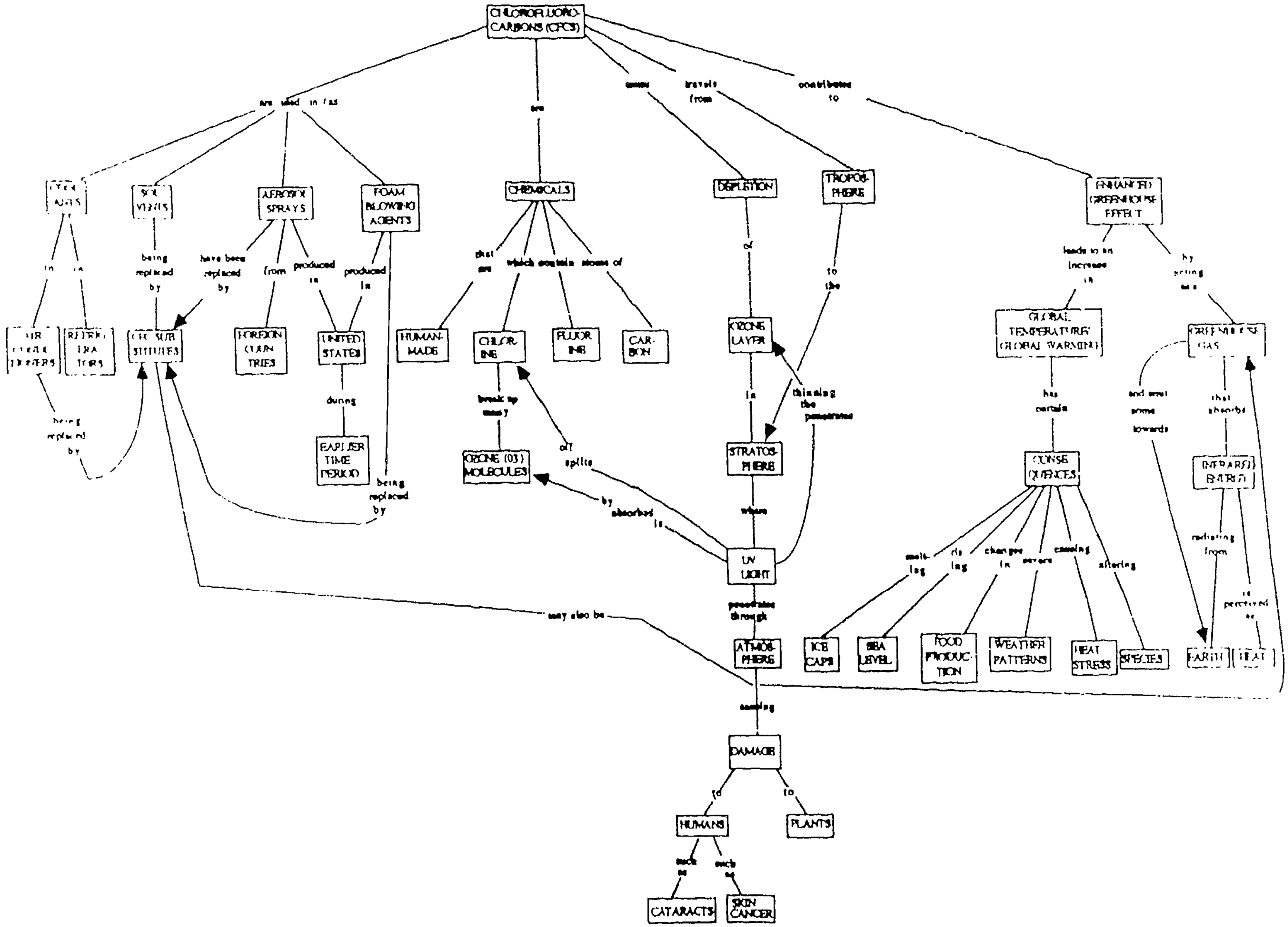

Figure 2. Teacher-expert concept map

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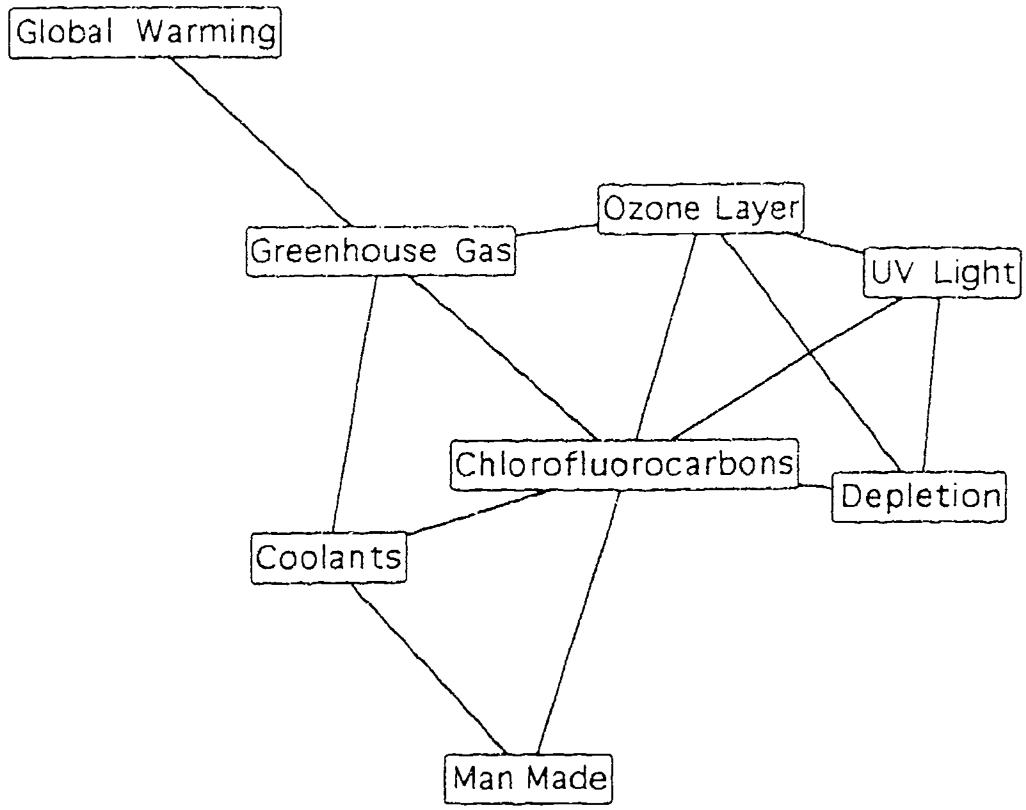

Figure 3 Teacher-expert Pathfinder Network

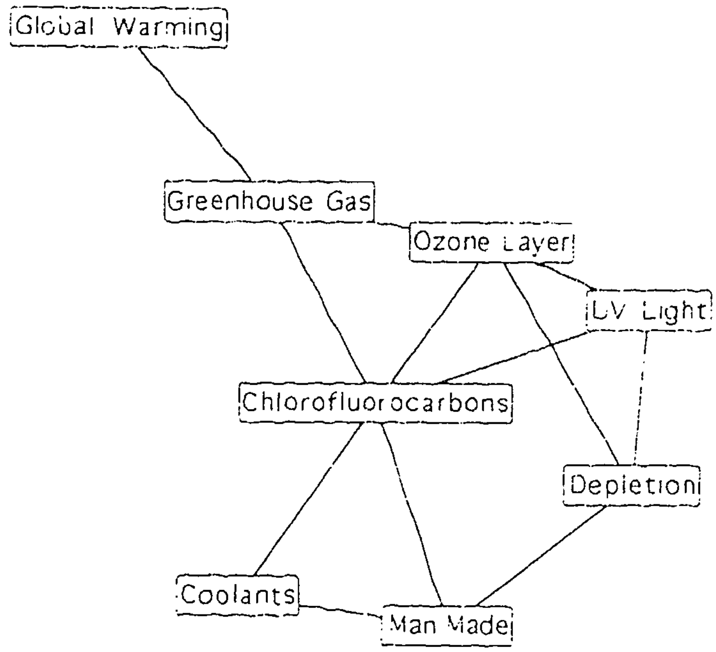

Figure 4. Pathfinder Network of the student with the highest PFNSI

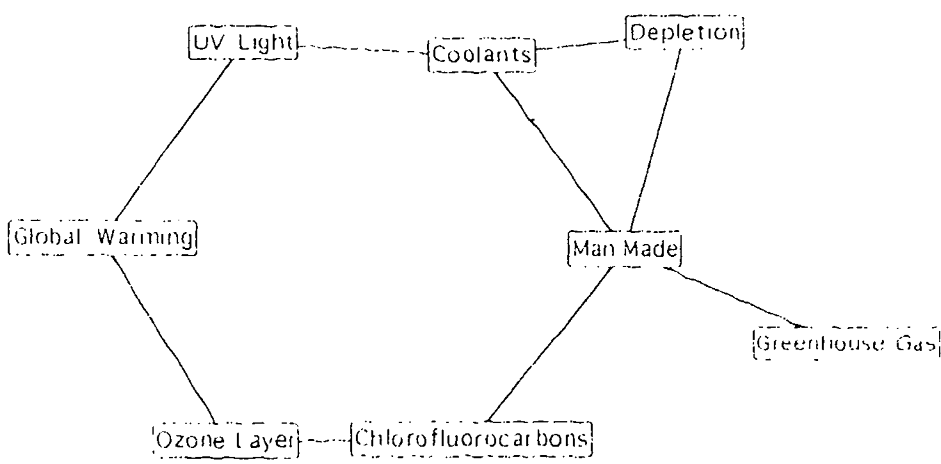

Figure 5. Pathfinder Network of the student with the lowest PFNSI

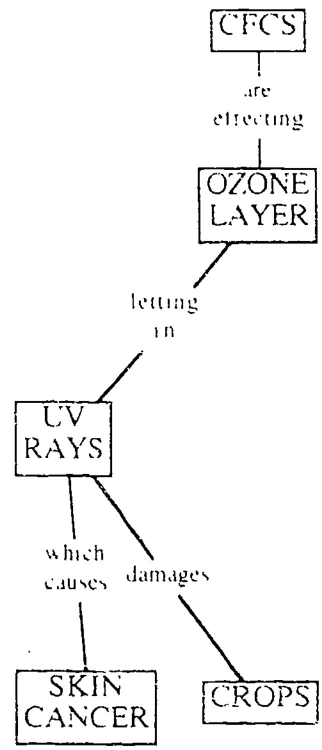

Figure 6. One of the least complex concept maps emergent from POSTIMCI

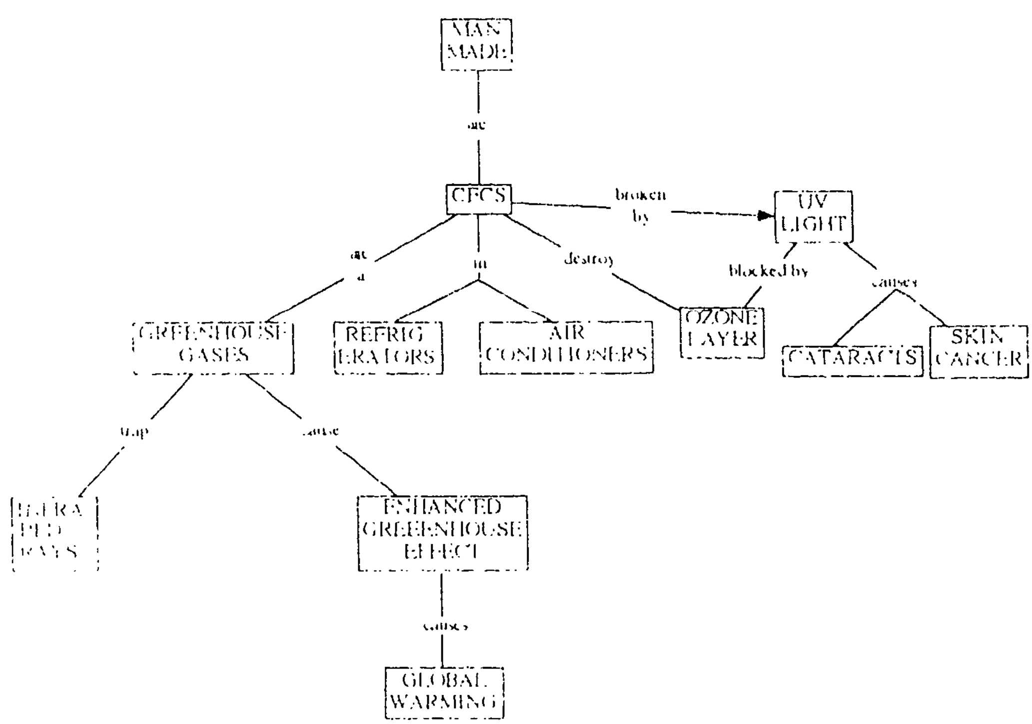

Figure 7. One of the most complex concept maps emergent from POSTIMCI

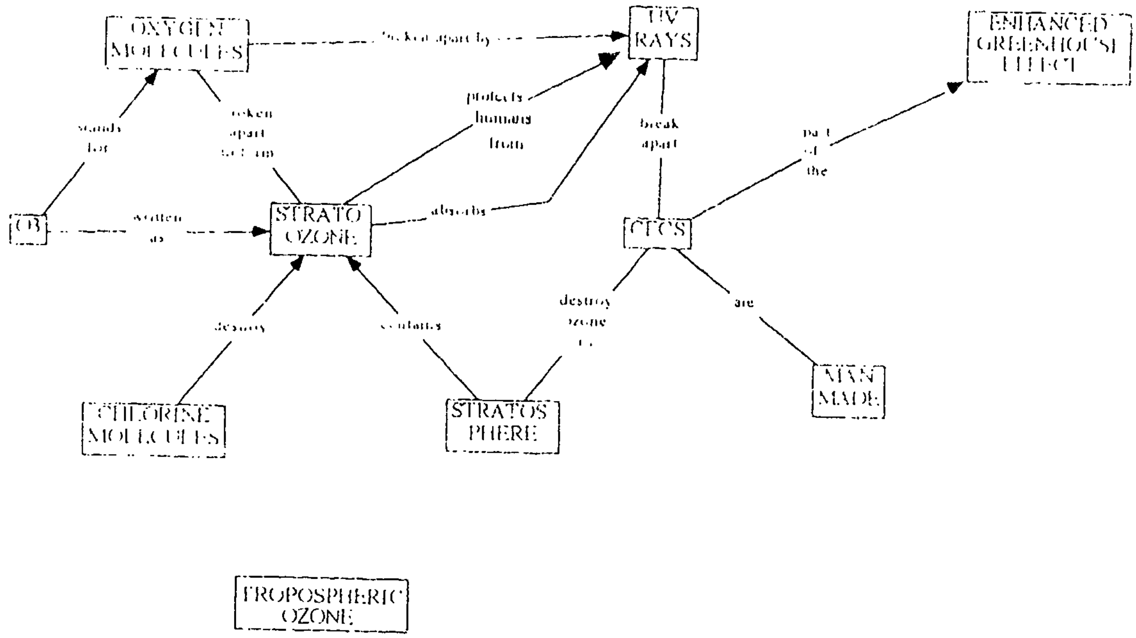

Figure 8. Hybrid-type concept map emergent from POSTIMCI

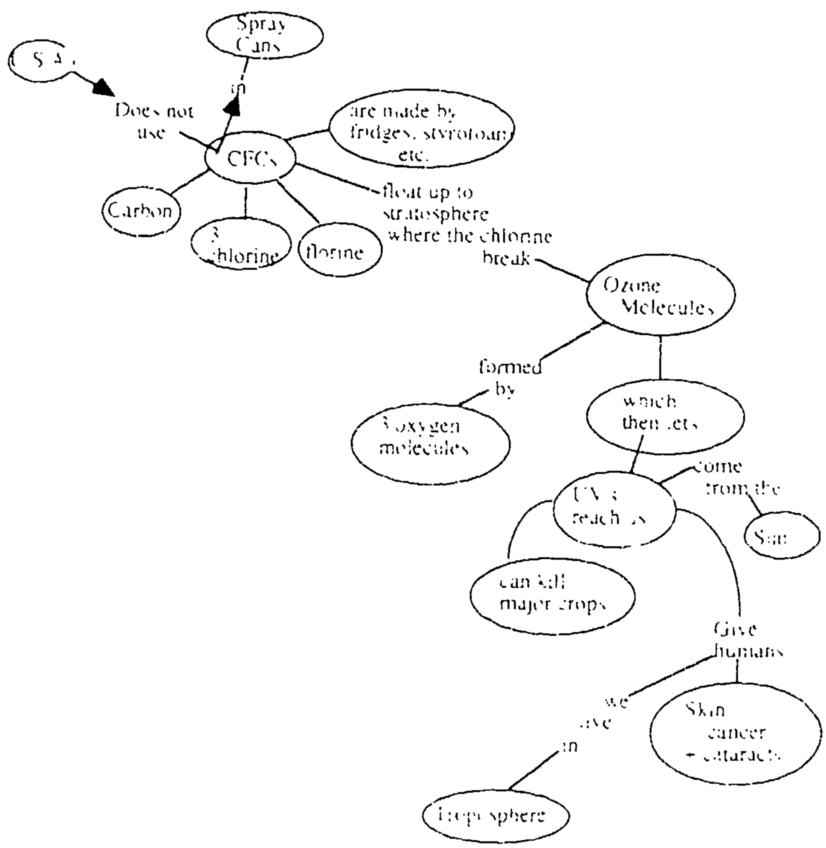

Figure 9. Concept map "notes" drawn during quiet time by POSTICCI student

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Table 1

Questions to Elicit Students' Conceptual Understandings about CFCs in All Interviews

1	In your thinking, what are CFCs?
2	Where do CFCs come from?
3	What, if any, problem is caused by CFCs?
3a	How do CFCs cause (problem cited by student)?
3b	I believe (problem cited by student) is a problem because.
4	Now, is there anything else you remember or would like to tell me about CFCs?
5	What else, if anything, would you like to tell me about any problems caused by CFCs?

Table 2

Questions in Post-Instruction Concept Interviews to Elicit Students' Views on the Interview as a Means to "Tell What You Know"

Questions Posed to All Students

1 What are your views and opinions about this interview as a way to help YOU think and talk about CFCs?

2 I am interested in things you found helpful in the interview as well as things you believe should be changed or added to make the interview more helpful.

(a) What, if anything, do you believe was helpful?

(b) For what reason or reasons was (____ ____ __) helpful?

(c) What, if anything, do you believe needs to be changed or added?

(d) For what reason or reasons should I change or add (____ ____ __ __)?

Additional Questions Posed to Students Undergoing POSTIMCI

3 What, if any, (other) comments do you have about the concept mapping that you did as a part of this interview?

4 Imagine that you went through this same interview, but without doing the concept mapping:

(a) Do you believe your answers to the questions about CFCs would have been the same as you gave me today, or would your answers have been different?

(b) Please tell me your reasons for saying this ?

(c) If student responds "different" to (a), ask: In what ways would your answers have been different if we had not done the concept mapping?

5 In what ways, if at all, did you make use of the concept map during the interview ?

6 How, if at all, did the concept map influence your thinking to the interview questions about CFCs?

7 In your opinion, was drawing and having the map helpful or not helpful to you in telling me what you know about CFCs?

(a) If students says "helpful" ask: For what reason or reasons was having the map helpful?

(b) If student says "not helpful" ask: What, if any, ideas do you have that WOULD make drawing/having the map helpful?

Table 3

Descriptive Statistics for Results of POSTICCI and POSTIMCI on Dependent Variable Measures of Conceptual Understanding.

Dependent Variable	POSTICCI (n =17) Range	Mean	Std Dev	POSTIMCI (n =17) Range	Mean	Std Dev
Accordance						
ACCORDC	6-26	18.89	6.07	4-28	16.71	6.22
ACCORDR	1-24	14.89	6.29	2-24	14.00	6.04
ACCORD	7-49	33.77	12.07	6-49	30.71	12.14
External Relatedness						
EXTERNC	1-17	4.06	3.68	0-13	3.35	3.00
EXTERNR	1-12	3.65	2.74	0-12	3.06	3.15
EXTERN	2-29	7.71	6.22	0-25	6.41	6.02
Interrelatedness						
INTER	0.29-1.04	0.79	0.17	0.5-1	0.82	0.16

Note. ACCORD and EXTERN represent the sum of the concepts (ACCORDC or EXTERNC) and relationships (ACCORDR or EXTERNR) explicated by each student.